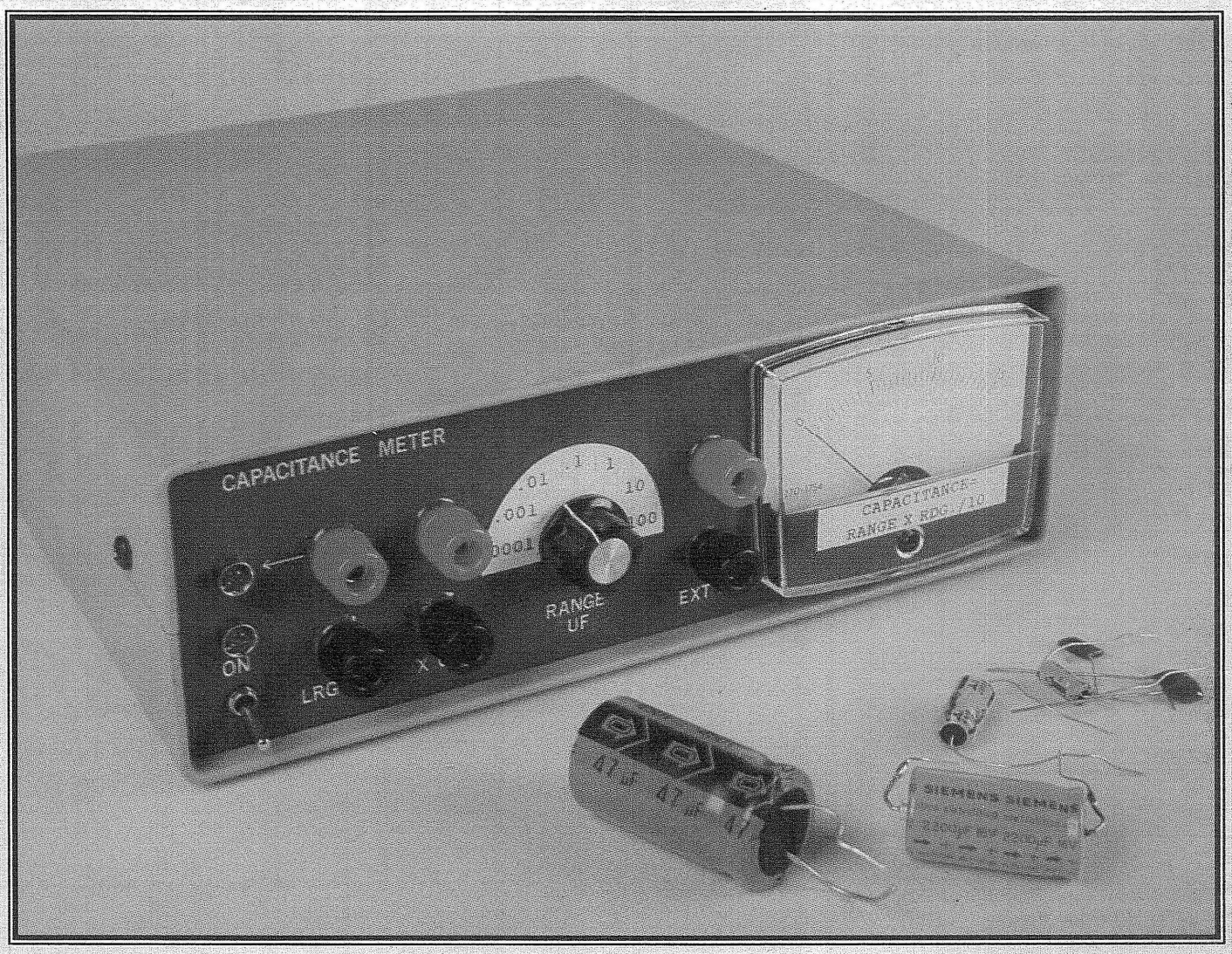
BUILD A CAPACITANCE METER

by Richard Schroeder



If you're like most electronic hobbyists, you have a whole box full of miscellaneous capacitors. These are the ones left over from various experiments and some of your projects. Or, perhaps you're the kind that can't resist buying those $2.00 grab bags that always seem to include hundreds of capacitors with strange markings.

No matter how you obtained these capacitors, you probably wish there was some easy way to get them tested and put back in service. Well, there is!

The capacitance meter described in this article will get the job done, and at the same time teach you some important principles regarding capacitors and the circuitry involved in testing them.

This instrument features an accuracy of around three percent using the built-in analog meter, or an accuracy approaching one percent using an external digital meter for which it provides. It covers a range of 150 picofarads to 150 microfarads in seven decade steps. It should be noted, however, that values as low as 20 picofarads can be measured on the lowest range as well.

The instrument also has a feature whereby it can measure very large capacitors with values of 50,000 microfarads or more. This feature uses the on time of an LED in conjunction with an external clock. This same LED will also indicate shorted or very leaky capacitors.

Our capacitance meter features DC biasing (or stressing) of the unit under test, which is a far more realistic way of measuring any capacitor, but especially the electrolytic types.

One final feature that deserves mention is the meter protector. This circuitry guards against connecting a capacitor too large for the setting of the range switch, which otherwise could damage the meter.

THE CIRCUIT — HOW IT WORKS

Please refer to the block diagram. The lower part of the diagram shows the blocks that are concerned with the ranges you will use most of the time, namely the ranges up to 150 microfarads. The upper block shows the system used to test the really large capacitors. This block will be explained later.

Consider first the four basic blocks — the triangular wave generator, the range resistor/s including the capacitor under test, the peak-to-peak (PP) detector, and the DC meter.

The triangular wave generator in our system supplies about 3 volts PP to one side of the capacitor under test. The frequency of the wave form is about 100 Hz but very stable. This signal comes from a very low impedance source that has the amount of power capability required for all, but especially the larger value capacitors.

Look at the next block. It shows the capacitor under test and a range resistor. Actually, there are six range resistors and a rotary range switch which selects only one at a setting. Note that the resistor connects from the output side of the capacitor and ground. In this configuration, the capacitor becomes a differentiator and as such, the wave form that appears at the capacitor/resistor junction is a square wave. This square wave will always have a PP voltage that is directly proportional to the capacitance value, and it is this voltage that ultimately reads out a value of capacitance.

The next block contains the peak-to-peak detector. This detector amplifies the square wave signal and then converts both polarity peaks to a single polarity DC voltage which then drives the meter.

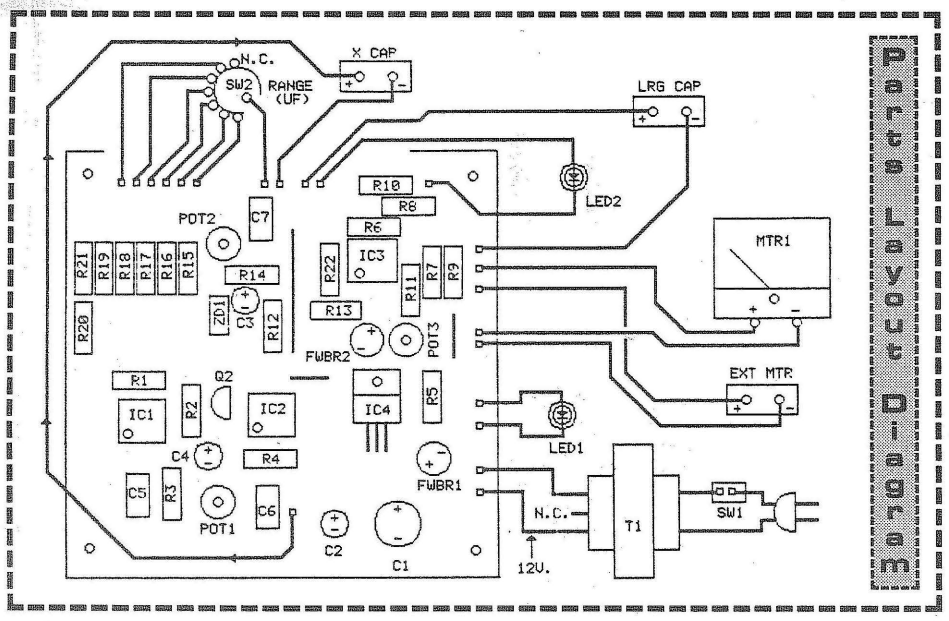
The last block needs only a little explanation. It shows the meter and also the terminals that will accommodate a digital meter. In this latter case, the meter must be set to read DC volts in the range of 1 or 2 volts.

The internal meter recommended for this project is actually designed to read DC volts, but the "DC VOLTS" label gets removed, allowing the operator to view the scale figures (in conjunction with the range switch setting), as values of capacitance. The same principle applies when an external meter is used.

The upper part of the block diagram shows the large capacitor measurement system. In this system, when the capacitor is first connected to the terminals, the LED comes on and stays on for a period directly related to the actual capacitance. The on time relationship is: 1 second per 1000 microfarads. For example, the popular 2,200 microfarad capacitor will cause the LED to stay on for 2.2 seconds. Obviously, the operator will need a stop watch or clock of some kind, but even so, here is a system that will accommodate those large capacitors that most capacitance meters can't handle.

This measuring system also serves to test any capacitor for excessive leakage or shorts. In this case, the LED simply stays on indefinitely.

Let's consider now how each block



Parts Layout Diagram

works in greater detail, starting with the triangular wave generator. Please refer to the schematic diagram.

IC1 is the world famous 555 timer chip configured as a free running oscillator, or multivibrator to be more exact. Usually, the normal square wave or pulse wave output of this IC is used to do the work. However, in our case, we use the triangular wave form which is in fact available at pins 2 and 6, which is also the high side of capacitor C5. Though the wave form we need is present at this point, it doesn't have the current or power that we need to ultimately drive the capacitors.

Here is where the FET (Q2) comes to the rescue. Note that the triangular wave feeds the gate of the FET, which, in turn, is configured as a source follower. With this arrangement, the triangular wave appears at the source element of the FET without any loading of the original signal, and the signal can then be used to drive the next stage.

From the FET source, the signal is capacitor coupled to the high end of trim potentiometer POT1 which, in turn, feeds the input of a small power amplifier (IC2) . The capacitor blocks the DC voltage that is present, but passes the signal along. This one trim potentiometer is the master calibration device for all the ranges.

The power amplifier serves to provide the triangular wave (at its output) with some current capability so that it can effectively drive the larger value capacitors. Its output wave form also has a 6 volt DC component that biases the capacitor under test. The need for power at this point can be better appreciated when one considers that a 150 microfarad capacitor has a reactance of around 10 ohms at the applied frequency.

Note now the range switch and range resistor set-up. Each resistor has a value that is one decade away from its neighbor, with the lowest value being 1 ohm, and the highest value being 100,000 ohms. These values are such that the developed square wave will have adequate amplitude for the next stage to process. You may find it interesting to know that a 1 microfarad capacitor (on the "1" range), develops the same amplitude square wave as a .1 microfarad capacitor on the ".1" range.

In connection with the range resistors (as seen on the schematic), it may at first appear that a range resistor is missing on the .00015 microfarad range. In effect, however, the resistor is there, because of R22 found at the non-inverting input (+) of op-amp IC3A. Though the low end of this 1 megohm resistor connects to a DC voltage point, the impedance at this point is so low it can be considered ground, and though the high end is connected to the range switch through a capacitor (C7), the capacitor has a reactance figure low enough to be considered a direct connection. In short then, this 1 megohm resistor becomes the range resistor for the .00015 range.

Because this resistor is effectively in parallel with each selected range resistor, and because this parallel effect will be more significant on the higher value resistors, R21 with a value of 10,000 ohms is connected in series with the logical range resistor used on the .0015 microfarad range. This scheme brings the total resistance back up to the required 100,000 ohms on that range.

Let's consider now the peak-to-peak detector and the meter circuitry.

As already discussed to some extent, the square wave signal gets coupled to the input of op-amp IC3 through capacitor C7. This op-amp is necessarily a BI-FET input type with an almost infinite input impedance. Any other type op-amp would present a detrimental loading effect across the range resistors.

In addition to detecting or rectifying, this stage also serves to amplify the rather weak square wave signal and provide the current and voltage required to drive the internal DC meter.

Note that the op-amp operates from the single 12 volt power supply bus. This is made possible by means of an intermediate power supply namely, the 6.2 volt point which comes from zener diode ZD1. Current for the zener is supplied through resistor R12 (470 ohms). Capacitor C3 in parallel with the zener prevents noise from developing and also helps keep the impedance at this point low. Because all of the op-amp input circuitry returns to this point, the op-amp thinks it is being supplied by the more traditional bi-polar supply.

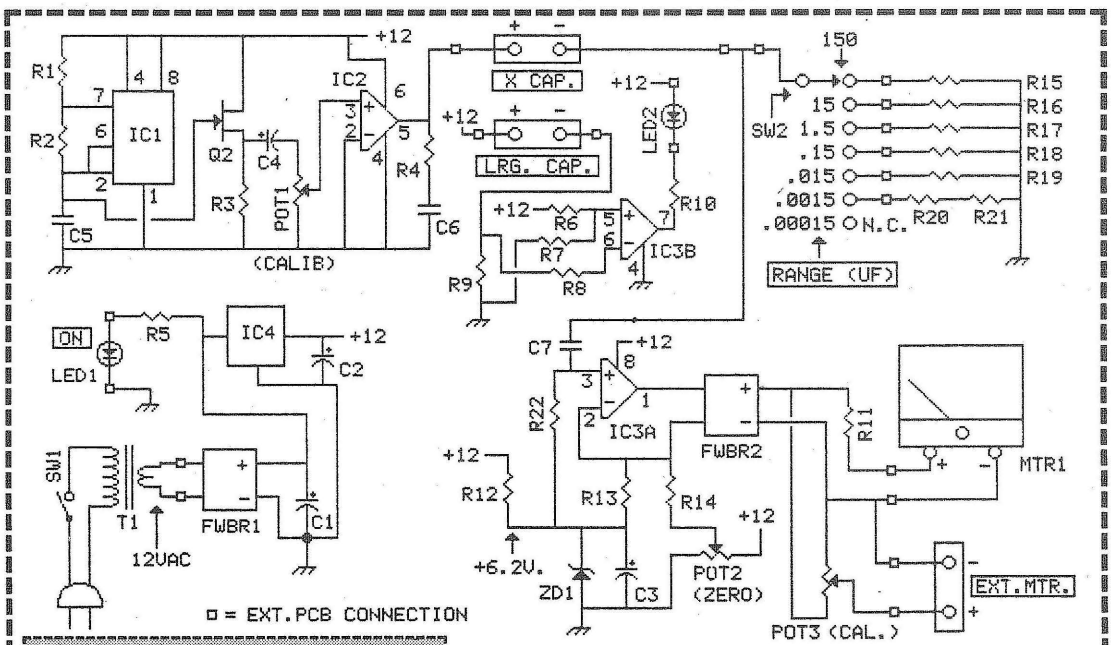
The amplified square wave gets rectified by means of full-wave-bridge-rectifier FWBR1. Note that one input to the rectifier connects to R13 and also the inverting input (-) of the op-amp. Keep in mind that all meter current flows through R13. This arrangement puts the entire rectifier system inside the negative feedback loop which corrects for the non-linearity of the rectifier.

Usually a large value capacitor is placed across a rectifier output for smoothing the wave form. Not so in our case because a capacitor is not really needed. We simply let the meter movement itself to do the required filtering of the pulsating voltage.

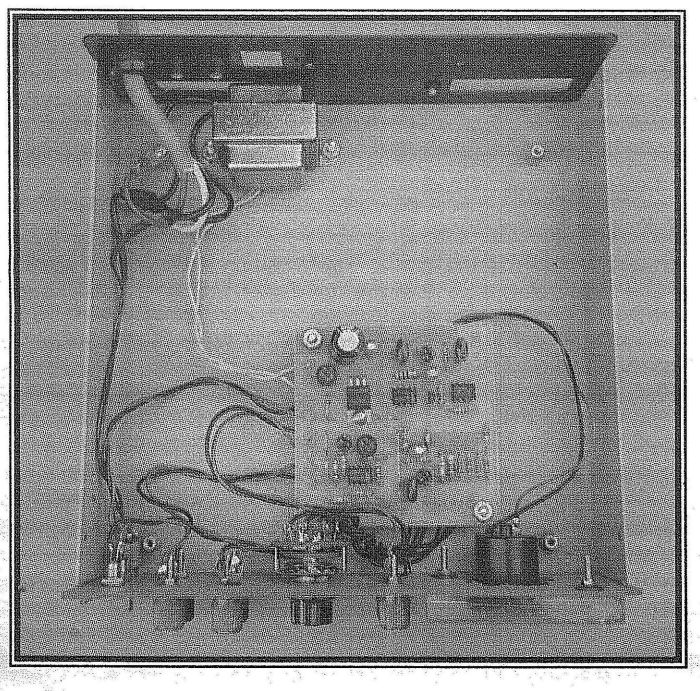
The ZERO trim potentiometer POT2 and its associated resistor (R14) is necessary to compensate for normal offset voltage (in the op-amp) which might otherwise cause an up scale meter reading with no capacitor under test.

Resistor R11 (1.8K ohms), in series with the meter, is provided to allow enough voltage across the rectifier output to drive the external meter when it is used. This resistor also provides current limiting to protect the meter even under severe overload conditions. Trim potentiometer POT3 is used to set the external voltage to 1.0 volt DC when the internal meter reads "10."

The meter chosen for this project is a Radio Shack unit designed to measure 0 to 15 volts DC. Its scale markings work nicely in our project in that the 10 mark being only two thirds of the way up scale, allows for over-range reading. For example, the popular .01 microfarad unit could be measured on this scale even if its actual value was more like .013 microfarads. Consider that if the meter had an upper scale limit of only 10 the same capacitor would have to be measured on the .1 range which would greatly reduce reading accuracy.



Schematic Diagram



It should be obvious at this point that when using the instrument, a simple formula has to be used to determine the actual capacitance, as follows: CAPACITANCE EQUALS METER READING TIMES RANGE SETTING, DIVIDED BY 10. After using the instrument a few minutes, you will automatically think of the 10 as a 1, which will simplify the formula. You will notice an abbreviated form of this printed on the meter face.

Let's consider now how the instrument measures large capacitors — those above 150 microfarads. Look at IC3B. It is configured as a voltage comparator with its output driving an LED (LED2). Its non-inverting (+) input is biased or referenced at 4.35 volts DC by reason of R6 and R7 which act as a voltage divider from the +12 volt bus. This bias holds the comparator in a state that keeps the LED off. The other input of the op-amp connects to resistor R9 (1K ohm) through a series resistor. Note that one of the large capacitor terminals connects to the +12 volt bus, and that the other connects to the ungrounded side of R9.

With all this in mind, what happens

when a large capacitor is connected to the test terminals? At the instant the connection is made, 12 volts appears at the high end of R9 which also appears at the input of the comparator, which, in turn, makes the comparator change state and turn on the LED. This condition remains until the capacitor reaches a voltage charge that exceeds the bias voltage, at which time the comparator will change back to its idle state and turn the LED off. Because the resistor is 1000 ohms and the comparator bias is 63% of 12 volts, the time constant (as indicated by the LED) is 1 second per 1000 microfarads.

The power supply for the unit is quite simple, consisting of a 12 volt transformer, rectifier, capacitor, and a voltage regulator. It supplies a regulated 12 volts DC at a current of around .060 amps. The pilot LED operates from the unregulated 17 volt point that feeds the regulator (IC4).

CONSTRUCTION

You will probably want to start with the building of the circuit board. Refer to the parts layout diagram and install the components as shown, if you are using a printed circuit board (PCB).

If you are using the perf-board method of construction, it is suggested that you still follow the same general layout. Keep in mind that the diagram shows the component view, not the copper trace view. If you will be making your own PCB from the pattern shown in this article, remember that the pattern must be placed in such a way that the final product will show the "CAP" lettering in a readable direction when looking at the copper side of the board.

When installing the components on the PCB, pay close attention to any polarity markings on the components such as the ± markings on electrolytic capacitors, and the color bands on the diodes. Then, of course make the orientation agree with the diagram. Use good quality solder and be careful to assure good connections while avoiding solder bridges between traces. When the components have been installed and checked, you are ready for the testing and adjusting procedure.

TESTING AND ADJUSTING

For this operation I recommend that you cut, strip, and tin all the wires needed to connect all the external components to the board. These will include the transformer, meter, range switch, LEDs, and terminals.

Concerning the Radio Shack meter, do not use the auxiliary resistor that comes supplied with it when purchased. Simply make direct connections from the meter terminals to the PCB.

If you will connect all the components using flexible wire cut to lengths of around 6 inches, you will find that these for the most part can be left in place when the whole assembly is installed in its enclosure. Also, the wires can be soldered directly to the pads on the copper side of the PCB rather than poking them through those little holes (if you desire).

When all the external parts have been wired to the board, spread the whole assembly out on the bench. Set the range switch to .01, the trim potentiometers to mid-range, and apply power.

If all is well, the meter pointer, after a quick up scale movement, will sit at or close to zero. The pilot LED will be on and the large capacitor LED will be off. If it seems to pass this test, adjust the ZERO trim potentiometer (POT2) for a meter reading of 0. Next, connect a .01 microfarad to the appropriate terminals and adjust the master calibrate trim potentiometer (POT1) for the correct meter reading (10). With the meter reading 10, check the voltage at the external meter terminals with your digital meter and adjust the cal potentiometer (POT3) for 1.0 volts DC.

These calibration adjustments would best be made using a 1% type capacitor. Perhaps you have one. If you don't have one and don't feel like investing in one or more precision capacitors, you might try this calibration scheme. Temporarily connect in parallel, 10 capacitors of the 10% type and of the same value. There is an excellent chance that these ten will average out to a value much closer to absolute than a single off-the-shelf 10% unit.

You may note a slight up scale meter reading on the .00015 range with no capacitor in place. This is normal, and one need only subtract those few picofarads from the reading when a capacitor is under test.

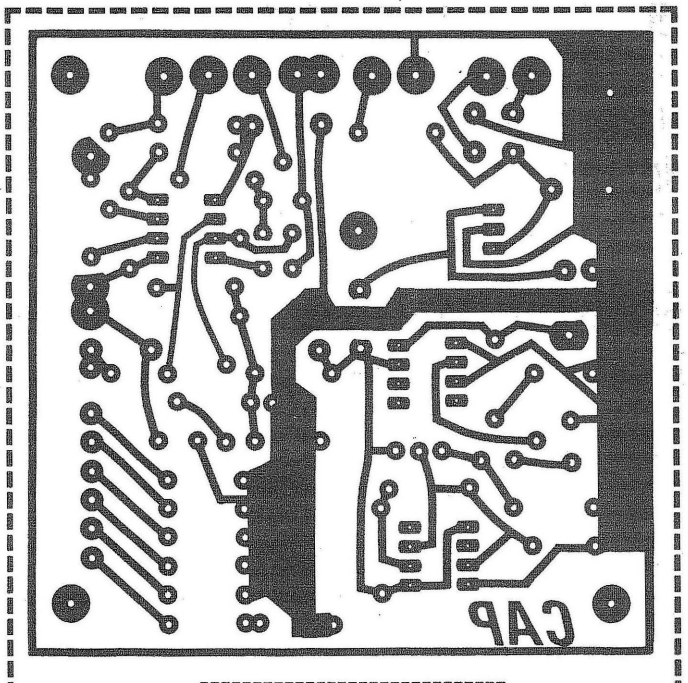
To test the large capacitor measurement system, simply connect a capacitor of say 2,200 or maybe 10,000 microfarads to the appropriate terminals and count the seconds that the LED is on. Remember, 1 second per 1000 microfarads.

When everything is working properly, put in all in a nice looking case. The case shown was obtained at ABC Electronics, Pomona, CA, for only $5.00, and it included reusable front and rear covers as well as a molded line cord and fuse. A little paint and some press-on lettering gave the instrument a professional look. The pictures should help you in positioning the major components.

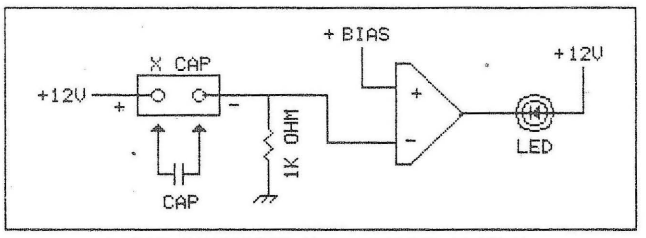
When mounting the PCB onto the floor of the enclosure, be sure that the circuit ground trace gets grounded to the metal. The DC VOLTS label (on the meter) can be blocked out with white correction fluid. Be very careful to avoid damaging the pointer when removing and replacing the meter cover. The "formula" was first typed on paper, cut to fit, and then glued to the black cover insert.

If you experience any problems in getting the instrument to work properly, the following two points would be the most logical places to check first: 1) +12 volt and +6.2 volt buses; 2) output of power amp IC2 (3 volts PP on 6 volts DC). Oftentimes, a good visual inspection will uncover a poor connection, misplaced component, or a solder bridge.

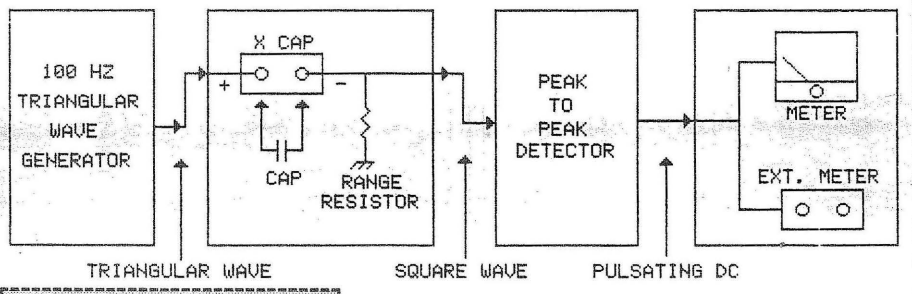
LET'S GET THOSE CAPACITORS TESTED! **NV**



PCB Layout



LARGE CAPACITOR MEASUREMENT SYSTEM



Block Diagram

Up to 150 Microfarad Measurement System

PARTS LIST

(RS = Radio Shack part #)

RESISTORS
(all 1/2 watt, 5% tolerance, carbon, unless otherwise noted)
R4: 10 ohms
R13: 100 ohms
R12: 470 ohm
R1,R9,R10: 1K ohm
R11: 1.8K ohm
R3,R5: 2.2K ohm
R7: 10K ohm
R6: 18K ohm
R2,R14: 68K ohm
R8: 220K ohm
R15: 1.0 ohm, note 1% type
R16: 10 ohm, note 1% type
R17: 100 ohm, note 1% type
R18: 1K ohm, note 1% type
R19,R21: 10K ohm, note 1% type
R20: 100K ohm, note 1% type
R22: 1.0 megohm, note 1% type

CAPACITORS
C1: 1000 microfarad, 25 or 35 volt, electrolytic, PC mount, RS# 272-1032
C2,C3,C4: 10 microfarad, 25 or 35 volt, electrolytic, PC mount, RS# 272-1025
C5,C6: .1 microfarad, 50 or 100 volt, mylar, 10% tol., RS# 272-1069
C7: .22 microfarad, 50 or 100 volt, mylar, 10% tol., RS# 272-1070

POTENTIOMETERS
POT1, POT2, POT3: 10K ohm, trim type, RS# 271-282

LEDS
LED1, LED2: mounted panel type, RS# 276-036

TRANSISTORS
Q2: 2N3819, RS# 276-2035

ICS
IC1: 555 timer, RS# 276-1723
IC2: LN386N audio power amplifier, RS# 276-1731
IC3: LF353N or TL082 dual bi-fet input op-amp, RS# 276-1715
IC4: 7812 voltage regulator, 12 volt, RS# 276-1771

SWITCHES
SW1: S.P.S.T. miniature toggle
SW2: single pole 12 position rotary (only seven positions used), RS# 275-1385

DIODES (rectifiers)
ZD1: 1N4735, 6.2 volt zener diode, RS# 276-561
FWBR1: 1.5 amp, 100 volt, molded round case, RS# 276-1152
FWBR2: 1.5 amp, 100 volt, molded round case, RS# 276-1152

METER
MTR1: DC voltmeter, 0-15 volts DC, RS# 270-1754

TRANSFORMER
T1: 12 volt, .450 A. Note: center tap (CT) OK but not used, RS# 273-1365

MISC.
Case, line cord, terminals, #6/32 nuts/bolts, press-on lettering, etc.

ABC ELECTRONICS
1210 S. Garey Avenue
Pomona, CA 91766